10.—Australites of mass greater than 100 grams from Western Australia

by W. H. Cleverly[1]

Manuscript received 20 November 1973; accepted 18 June 1974

Abstract

Seventeen australites from Western Australia in the mass range 100-437 g and including the most massive australite known have been examined. Most of the other fifteen previously recorded Western Australian specimens in that range have been re-examined. All are round, oval or dumbbell shaped cores. Where possible, the forms and dimensions of the primary bodies have been assessed and thence the percentage losses involved in forming the remnant cores. Average volume loss was only 46%. The distribution of the sites of find has been considered and the south western portion of the state is confirmed as the principal area of infall of australites of mass exceeding 100 grams. The distribution suggests the possibility of mass grading related to the northern boundary of the australite strewnfield.

Introduction

Australites (Australian tektites) of mass exceeding 100 g are rare, comprising only a few hundredths of one percent of known specimens. The purposes of this paper are to describe 17 Western Australian specimens in the mass range 100 to 437 g and to supply additional details for any other available specimens for which published descriptions are incomplete.

Because all australites under consideration are remnant shapes from which a stress shell has spalled, they have certain morphological features in common. A general procedure was therefore possible when examining the specimens.

General principles and procedure

Larger specimens were weighed on a Mettler, K-type, top-loading balance which had also arrangements for bottom suspension of the specimen in de-ionized water for determination of specific gravity; for lighter specimens and chips, a more sensitive chemical balance was used (Table 2, cols. 6 & 8).

The conventional statement of dimensions in the sequence length, breadth and thickness (Table 2, col. 7) has a simple relationship to australite orientation during flight downwards through the atmosphere. Because nearly all australite primary bodies were either spheres or rotational shapes with considerable symmetry, they almost invariably adopted a stable flight orientation, generally presenting a broad face forward. Thus the length and breadth (or a diameter) were in a plane normal to the line of flight and the thickness was parallel to the line of flight. The thickness was especially reduced during flight and the length and breadth were also affected, but the same relationship of the dimensions to the flight orientation generally applies to the remnant core as for the primary body. The plan view in flight position is thus a view of the posterior surface of flight looking in the direction of flight and this view shows length and breadth or diameter. The plan view dimensions of australite cores are often but not necessarily defined at the level of the rim (see below).

The shape type of the core (Table 2, col. 2) is the shape seen in plan view. Ideally, a round core is perfectly circular in plan view. Weathering may lead to differences of 2-3 mm in the dimensions of a core of (say) 50 mm diameter, but classification as a round core may be preferred. Similarity of the various profiles through the posterior pole of the core is also a criterion which aids the distinction between round and broad oval cores; the distinction is none the less subjective. The arbitrary width/length ratios of Fenner (1940 p.312) were applied strictly in defining broad oval, narrow oval and boat shapes, resulting in a nomenclature change for one previously described specimen (No. 28, Table 2). The dumbbell shape is self-explanatory.

Most well-preserved large cores have a rim separating the posterior surface of flight from the surface exposed by loss of the stress shell. The posterior surface is a modified remnant of the surface of the primary or parental body which suffered shape modification during passage downward through the earth's atmosphere. The form of the posterior surface is thus a guide to the form and dimensions of the primary body. The stress shell was a shell of glass a few millimetres thick immediately beneath the anterior surface of flight where fusion and ablation stripping were active during the earlier hypersonic phase of atmospheric transit. The shell had been first heated and then cooled. Opinions differ as to the timing of the loss of the stress shell—whether in a late stage of flight, on impact, or as the result of terrestrial processes such as diurnal temperature changes. Small cores retaining partially detached portions of the stress shell are not uncommon, but specimens of this kind (known as "indicators") are unknown amongst cores of mass exceeding 100 g, evidently because the greater total amount of expansion and contraction resulted in a more efficient spalling of the shell. The surface exposed by loss of the stress shell may be relatively irregular when compared with the posterior surface.

Thus, on well preserved cores, the relatively smoothly curved posterior surface terminates at a rim anterior to which the dimensions decrease

[1] W.A. School of Mines, P.O. Box 597 Kalgoorlie 6430. Honorary Associate, Western Australian Museum, Perth.

to those of the surface exposed by loss of the stre s shell. Correct interpretation of the "facing" of the rim is critical to identification of the posterior surface of flight and hence to deductions concerning the form and dimensions of the primary body. In a few specimens, terrestrial weathering has removed or considerably modified parts of the rim, but in only one of the specimens under consideration was the flight orientation in doubt.

Anterior to the rim on the surface exposed by loss of the stress shell (the present anterior surface as distinct from that of flight) there may be a distinct shoulder inherited from the ablation form (see for example Fig. 3-17). In such examples an equatorial zone is defined between the natural limits of rim and shoulder. In others, the shoulder is indistinct or absent and the anterior limit of the equatorial zone is then ill-defined, or the zone may exist only in the sense that it usually has a distinctive minor sculpture (Fig. 2-9).

The form of the posterior surface was estimated by fitting curves to profiles traced on enlarged silhouettes projected with a lantern, the specimen being oriented as in flight. The degree of enlargement used (about ×4) was calculated for each by comparison of the dimensions of the silhouette with those of the specimen. Profiles were traced on cm-mm graph paper with the rim of the specimen aligned with one set of lines of the paper.

When a core is circular in plan view, or nearly so, and the constructed arcs of circles fit closely the various profiles through the posterior pole of the specimen as seen in side elevation and have much the same radius, it is assumed that the primary body was a sphere.

When a core is elongate and the posterior surface has distinctly different transverse and longitudinal profiles in side elevation, a simple possibility is that the parent body was a prolate spheroid which oriented with the long axis normal to the flight path. For such spheroids the radius of the arc fitted to the transverse profile through the posterior pole is identical with the semi-minor axis of the elliptical longitudinal profile. The mathematical origin of the ellipse was plotted, and by using the co-ordinates of a point on the best preserved part of the longitudinal profile in the general equation of the ellipse, the semi-major axis was calculated. The positions of the foci were then calculated and an ellipse drawn to test the correctness of fit. Except when badly eroded (e.g. No. 28) these specimens presented little difficulty.

When a core is round and all profiles through the posterior pole are closely the same ellipse, the core was probably derived from an oblate spheroid which oriented with the short axis parallel to the flight path. Unlike the previous example, neither semi-axis of the ellipse is directly measurable. The method used was to judge the approximate position of the major axis, calculate the ellipse as before, and draw a trial ellipse on tracing paper superimposed on the diagram. The position of the major axis was then adjusted 8 mm (i.e. c. 2 mm on true scale) and the calculation repeated. In general, three or four trials with reduced degrees of adjustment sufficed to produce a well fitting ellipse, the dimensions of which were known to 1 or 2 mm on true scale. Mathematical methods could probably be devised e.g. by fitting a regression line to points selected from the best preserved parts of the profile, but such methods tend to give a rather spurious aura of precision to these estimates based upon pitted and otherwise imperfect surfaces. Neither was a lens measure used in a quantitative way, but it was found to be a valuable aid for the detection of non-spherical surfaces. A narrow, double thickness (0.05 mm) of transparent adhesive tape with interleaved strip of cm-mm graph paper was attached along the profile to be examined to smooth out minor irregularities before applying the lens measure. Lens measure readings taken along six profiles outward from the posterior pole of specimen No. 5 (Table 1) illustrate the increasing degree of curvature towards the rim of a surface which, to the eye, appears to be part of a sphere (Chapman 1964 Fig. 6A).

Table 1

Lens measure readings for posterior surface of australite core from Lake Yealering

Distance between mid point of lens measure and posterior pole of core	Range of lens measure readings for six profiles	Mean lens measure reading for six profiles
cm	units	units
1	10.5–13	12.2
1.5	11.5–15	12 7
2	12–16	14 0
2.5	14–18	16 0
3	15.5–18 5	17.5

Arcs of circles will fit considerable lengths of ellipses to within the thickness of construction lines (see for example Baker 1956 Figs. 21, 31, 32). As ellipticity increases, the possibility of detecting departure from spherical shape improves and it is also better in those specimens where losses from the primary body have been relatively small. Blown sand or other terrestrial agents can cause complications e.g. by flattening the polar area of the spherical surface of a core to produce a form approximating an oblate spheroid. If an oblate spheroid with the short axis parallel to the line of flight is mistaken for a sphere, the volume of the primary body will be over estimated and likewise the percentage losses (see below). A round core calculated as a sphere and having unusually high loss figures may therefore be suspected as having been derived from an oblate spheroid.

The writer finds it difficult to believe that a prolate spheroid would be stable with the long axis parallel to the flight path, but if such a spheroid were incorrectly calculated as a sphere, the volume of the parent body would be under-estimated and this could become evident as unusually low percentage losses.

Table 2

Masses and dimensions of australite cores from Western Australia and of their primary bodies

No.	Shape Type	Site of find	Long E.	Lat. S.	Mass g	Dimensions mm	S.G.	Primary body: Dimensions cm	Primary body: Mass g	% Losses: Mass	% Losses: Depth	Source of Data
1	Broad oval	c.3 km W. of Notting	118°14′	32°27′	437·53	83·7 x 72·1 x 54·5	2·425	10·2 x 8·4 x 8·4	914	49	35	
2	Broad oval	c.16 km S.S.E. of Warralakin	118°41′	31°08′	(265) 238·00	(70) 65 x 62·5 x 42	2·409	8 x 7 x 7	....			Baker (1962)
									494	47	40	
3	Round	Newdegate	119°02′	33°06′	243·05	62 x 58·6 x 55·1	2·424	6·4 diam.	333	37	14	
4	Broad oval	c.14 km W. of Kondinin	118°07′	32°30′	233·92	64·8 x 58·9 x 50	2·435	7·4 x 6·4 x 6·4	386	38	22	
5	Round	Lake Yealering	117°38′	32°36′	218·05	67·9 x 66·9 x 41·4	2·433	7 x 7 x 5·1	318	46	19	
6	Broad oval	On W. end Lake Ballard	120°36′	29°21′	200·29	60 x 57 x 44	2·435	8·4 x 7·8 x 7·8	652	69	44	Cleverly (1971)
7	Broad oval	Narrogin or Narembeen	....	...	(200) 194·78	67 x 56·4 x (40·6) 39·3	2·437	8·6 x 7·1 x 7·1	557	64	43	
8	Round	c.18 km W. of Notting	118°05′	32°27′	194·40	57 x 55 x 49·5	2·423	6·4 diam.	333	42	23	
9	Round	c.19 km N. of Ongerup	118°28′	33°48′	184·07	55·6 x 55·5 x 48·6	2·423	5·7 diam.	226	19	15	
10	Dumbbell	Cuballing	117°11′	32°49′	175·996	100 x 42 x 33·7	2·435	....	....		....	Baker (1966)
11	Round	Graball			168·28	....	2·434	8 diam.	....	74		Baker (1963)
			118°34′	32°02′	...	60·9 x 58·7 x 37·5	....	....	653		53	
12	Round	5 km S.E. of Corrigin	117°54′	32°22′	167·98	56·9 x 55·8 x 43·8	2·427	6·6 x 6·6 x 6·4	358	53	31	
13	Round	c.25 km S.W. of Chillilup	118°25′	34°29′	167·28	56·8 x 56·3 x 44·5	2·410	6·4 daim.	331	49	30	
14	Round	Between Narrogin & Merredin	....	....	(c.154) 152	57 x 55 x 39	2·42	....	....	....	....	Simpson (1939)
15	Dumbbell	c.16 km N.W. of Ongerup			151·286	98·4 x 35·6 x 29·6	....	....	....	....	....	Baker (1967)
			118°21′	33°52′			2·433					
16	Broad Oval	Kalgarin	118°42′	32°30′	(149) 126·75	52·2 x 49·7 x 47·4	<2·439	5·4 x 5·1 x 5·1	180	17	7	
17	Round	Near Corrigin	117°52′	32°20′	147·00	54·3 x 52·9 x 41	2·434	6·7 diam.	383	62	39	
18	Round	Lake Grace	118°28′	33°06′	(143) 134·50	53 x 52·5 x 43·5	2·409	....	....	....	....	
19	Narrow oval	26 km E. of Kulin	118°26′	32°40′	(133) 131·49	79·6 x 43 x 30·2	2·420	8·3 x 4·8 x 4·8	242	48	37	
20	Round	Lake Buchanan	c.123°00′	c.25°30′	(120) 116·06	55·8 x 55·1 x 31·3	2·439	6·1 x 6·1 x 3·6	171	30	13	
21	Broad oval	Babakin	118°01′	32°07′	(117) 113·07	51·4 x 46·3 x 37·2	2·432	....	....	....	....	
22	Broad oval	c.8 km E.N.E. of Wickepin East	117°44′	32°45′	116·94	61·3 x 51·3 x 32·2	2·429	7 x 5 x 5	222	47	36	
23	Broad oval	Narembeen	118°23′	32°04′	(115) 114·55	46·9 x 45 x 43·6	2·430	5·1 x 4·7 x 4·7	141	19	8	
24	Round	Moulyinning	117°56′	33°14′	111·15	48·7 x 46·7 x 38·7	2·421	5·6 diam.	223	50	31	
25	Round	Norseman	121°47′	32°12′	110·57	51·6 x 50·9 x 33·9	2·432	5·4 x 5·4 x 4·2	156	39	20	
26	Round	c.3 km E. of Brookton	117°02′	32°22′	109·79	50·4 x 50·0 x 34·5	2·430	5·8 diam.	248	56	38	
27	Round	Eastern Goldfields of W.A.	....	...	108·30	52·4 x 50·5 x 33·9	2·437	5·4 x 5·4 x 4·4	164	34	23	
28	Narrow oval	c.42 km E. of Narembeen			107·457	....	2·431	....	...		...	Baker (1961)
			118°50′	32°04′	....	65·3 x 38·9 x 32·9	...	7·3 x 4 x 4	149	28	22	
29	Round	c. 11 km S.E. of Salmon Gums	....		102·37	46·4 x 44·6 x 38·0		....		....	....	Baker (1967)
			121°44′	33°03′		....	2·426	5·2 diam.	179	43	37	
30	Broad oval	c.10 km W. of Kurnalpi	122°09′	30°28′	101·12	54·7 x 43·8 x 32·3	2·445	7·5 x 5·7 x 5·7	312	67	43	
31	Broad oval	Karonie	122°28′	30°58′	100·80	49·3 x 47·1 x 34·9	2·432	6·3 x 6·1 x 6·1	298	66	43	
32	Broad oval	Jubuk	117°41′	32°21′	(>100) 86·80	(c.53) 47 x 49·1 x >33·8	2·427			....	....	

The dimensions of a spherical primary body are stated by the diameter; for a prolate spheroid, dimensions are in the form 6 x 4 x 4 cm and for an oblate spheroid, in the form 6 x 6 x 4 cm (Table 2, col. 9).

From the dimensions of the primary body as determined above and on the not inconsiderable assumption of mathematically perfect form, the volume was calculated. The present volume had been determined incidentally to the measurement of specific gravity. The total percentage loss could thus be calculated. With the further assumption that the primary body had the same specific gravity as the remnant core, the percentage loss of volume is also the percentage loss of mass. The total thickness loss from the primary body was calculated from a consideration of the thicknesses of the primary body and the remnant core.

Total losses from the primary body include those of fusion and ablation stripping during flight, spallation of the stress shell, terrestrial losses as the result of both chemical and physical processes, and the artificial damage of some specimens.

Losses as a result of certain terrestrial processes such as chemical etching by soil water and biochemical etching by plant roots and hyphal filaments cannot be estimated quantitatively. It is believed that such losses will not generally exceed a few percent if expressed as a percentage of the primary body and will usually be of a smaller order of magnitude than flight losses.

The losses, whether natural or artificial, of flakes which transect the otherwise smooth form of a core can be reasonably estimated by completing the form with modelling clay and converting the added mass of the clay to that of the same volume of glass. This was done wherever possible and the natural flake losses substracted from total losses. Restoration of artificial losses, which are characterised by the brilliant lustre of the exposed glass, enabled estimation of the mass of an artificially damaged specimen when found. The restored mass of an artificially damaged specimen is shown in brackets immediately preceding the existing mass (Table 2, col. 6); likewise a restored dimension immediately precedes the existing dimension (col. 7).

The loss figures given in Table 2 cols. 11 and 12 are thus essentially those arising from atmospheric flight or its aftermath (stress shell) but including also terrestrial losses which have been minimised by allowance for natural flake losses.

Australite primary bodies had a complex internal flow structure, the schlieren differing slightly in their chemistry; they also contained bubble cavities of various sizes and of irregular distribution. Arising partly from the consolidation of the initially molten primary body and

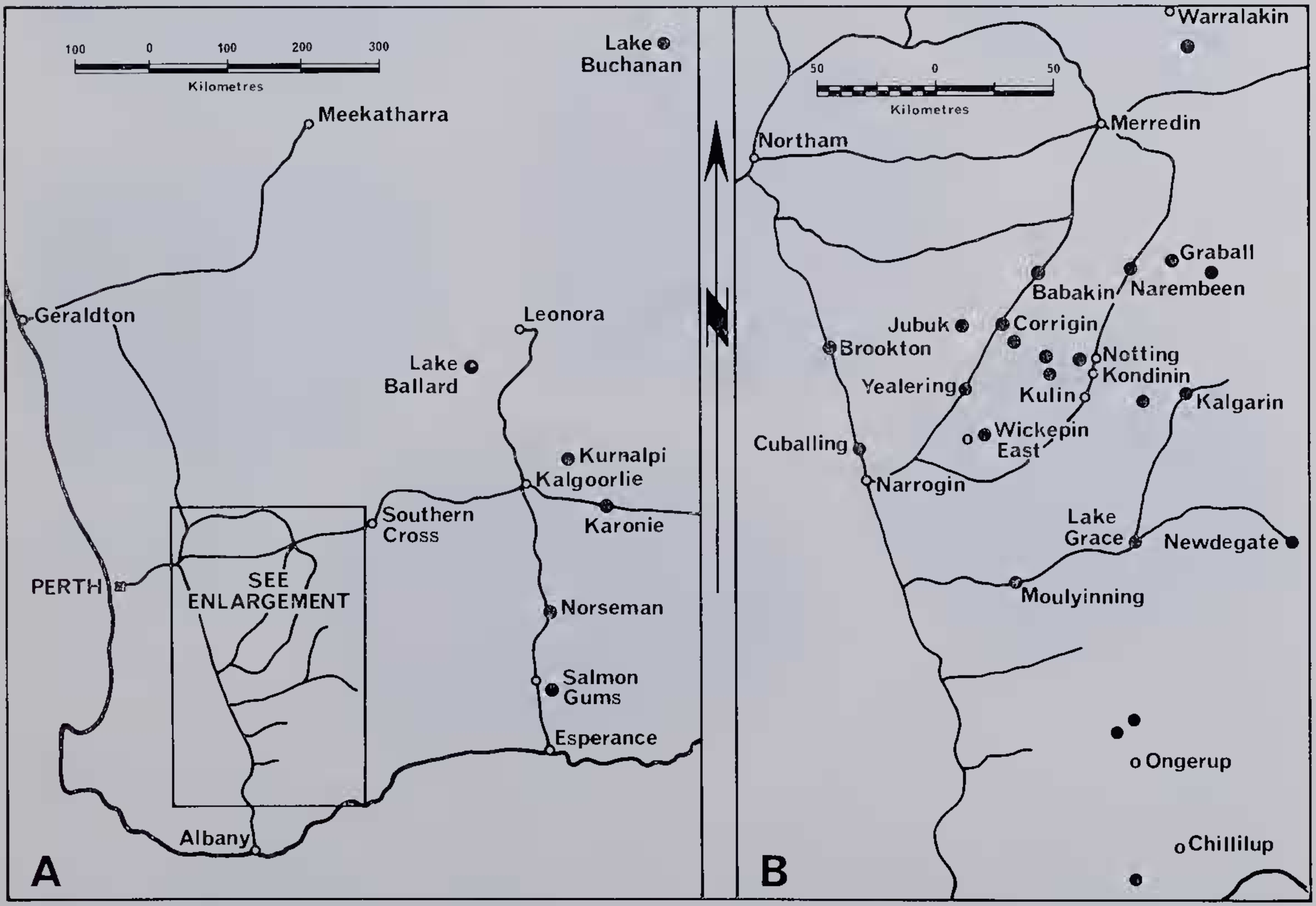

Figure 1.—A.—Sketch map of the south western part of Western Australia showing sites of find of australites of mass greater than 100 grams (solid circles.) in relation to some railway lines. B.—Enlarged portion of the same. The sites of Nos. 7, 14 and 27 (Table 2) are omitted for lack of sufficiently specific information.

from its heterogeneity, partly from stresses imposed by atmospheric transit and perhaps also by terrestrial processes, autralites retain various degrees of residual strain. Terrestrial processes developed a variety of minor surface sculptural effects such as gutters (for details see Baker 1959) which often reflect these internal heterogeneities and strains. The minor sculpture developed on some specimens was partially removed during a later episode of transport or exposure to blown sand. Other specimens which had been abraded became buried and were subsequently chemically etched by the constituents of soil water. The better preserved specimens show minor features of the posterior surface such as flow swirls (Fig. 3-12) which were probably original features of the primary body, now accentuated by minor degrees of etching. Only the more prominent surface and sculptural features are noted in the descriptive section below.

Descriptive Notes

This section should be read in conjunction with Table 2 which shows physical data of the specimens. Figure 1, showing sites of find, if specifically known, should also be consulted. The abbreviations W.A.M., S.A.M., and W.A.S.M. refer to accession numbers in the collections of the Western Australian Museum (Perth), South Australian Museum (Adelaide) and the W.A. School of Mines (Kalgoorlie) respectively. Descriptions follow in the number sequence of Table 2, col. 1.

1. Fig. 2. Cast: W.A.M. 13238. The original is owned by Mr. P. Repacholi, who found it in 1969 whilst ploughing to a depth of c. 15 cm in the N.E. corner of Avon Location 15085, about 3 km W. of Notting railway siding. It is the most massive australite known.

The form is much modified by natural flake losses which have removed the rim except for a 5 cm length along one side and a 1 cm length elsewhere. Resulting also from flake losses the posterior surface is less symmetrical than the anterior. Surface dating from the time of arrival on the earth's surface is considerably weathered, the sculpture comprising pits of 1-2 mm diameter transitional through oval pits into short gutters, and larger composite pits which contain two or three oval pits within them. Longer gutters are restricted to remnants of the equatorial zone where they are oriented approximately parallel to the flight path and to three larger flake scars in that zone where they are oriented approximately parallel to the rim. The largest and most recent flake loss has removed much of one end of the core and the scar is characterised by circular and lunate bruise marks and is dulled by abrasion. Artificial damage comprises a 2 cm trail of millimetre sized scars, perhaps attributable to contact with the plough.

The transverse curvature of the posterior surface can be reasonably estimated, but calculation of the elliptical longitudinal section had to be based principally upon a 5 cm length of pitted surface. Natural flake losses are equivalent to c. 3.5% of the mass of the primary body.

2. W.A.S.M. 8925. For a detailed description and illustrations of this specimen from near Warralakin, see Baker (1962).

3. Fig. 2. W.A.M. 12318. Found near Newdegate. Briefly described by McCall (1965) with illustration of the anterior surface. The form is sub-spherical (thickness/mean diameter ratio 0.91). No rim nor defined equatorial zone is present but there is a central girdle up to 2 cm wide characterised by a complex of gutters. The posterior surface has some patches of short gutters. The anterior surface, which is rather irregular, has some roughly circumferential gutters surrounding a complex of short gutters. The precise flight orientation, and hence the dimensions as conventionally stated, are in some degree a matter of opinion. Arcs of circles fit reasonably well the profiles of the posterior surface.

4. Fig. 2. Found by Mr. H. Biggin in 1940 or 1941 in the N.E. Corner of Avon Location 19835, about 14 km W. of Kondinin. Owned by Mrs. H. Biggin of "Karingal", Kondinin.

The specimen is fairly well preserved except for shallow natural flake losses from the posterior surface resulting in a tapered appearance in cross section. The longitudinal profile is not so badly affected and a reasonable estimate of the primary form is possible. There have been no artificial losses. The posterior surface, which is somewhat dulled by abrasion, has some circular and lunate scars and etched flow swirls. The equatorial zone is reasonably defined and has some short gutters, variously oriented. The anterior surface is asymmetrical in cross section and has composite pits containing short gutters and circular and lunate etched scars. Some of the gutters tend to be circumferential near the periphery. This suface is much like that of No. 1 which was found only 11 km distant.

5. W.A.M. 4455. Found on Lake Yealering which adjoins the Yealering townsite. Some details and illustrations of both surfaces were given by Fenner (1955), who noted the deeply pitted posterior surface and the unusual degree of development of gutters on the anterior surface (his Pl.VII Figs, 2, 1 respectively). Four views were figured by Chapman (1964, Figs. 6A, 7), who noted that gutters had been developed selectively on the surface exposed by loss of the strees shell. The diameter of 67.4 ± 0.5 mm is the largest for any known round core.

6. Owned by Mr. L. P. Berryman, who found it on Lake Ballard in 1968. Described and figured by Cleverly (1971).

7. Fig. 2. W.A.M. 12992. Found by an aborigine about 1920 and given to Mrs. C. Parrot; donated to the W.A. Museum by Mr. G. Woodland in 1969, by which time it was uncertain whether the site of find had been Narrogin or Narembeen (Fig. 1B).

Extensive but shallow flakes have been artificially struck from posterior and anterior surfaces, and an earlier, natural flake loss has removed the rim from around one end of the

Figure 2.—Australites from Western Australia numbered as in text and Table 2. In all elevational views the anterior surface is towards bottom of page. 1a.—Posterior surface. Length 83.7 mm. 1b.—Anterior surface. 1c.—Side elevation showing greater regularity of anterior than posterior surface. 1d.—End elevation. Width 54.5 mm. 3.—Elevation Angularity at upper left is the result of natural flake loss. Width c.60 mm. 4.—Side elevation. Length 64.8 mm. 7.—Side elevation. Length 67 mm. 9.—Elevation showing wedged anterior profile Width 55.6 mm. 12.—Side elevation. Width 59.9 mm.

specimen. The posterior surface has unusual pits containing narrow, parallel or divergent, short gutters developed on bundles of more etchable schlieren. The remaining rim is reasonably defined and regular. The equatorial zone has some short gutters oriented normal to the rim and also a patch of deep pitting. The anterior surface has some pits transitional into short gutters.

Because of artificial damage, the form of the primary body can be assessed only very approximately. It is possible that the transverse profile was elliptical i.e. that the primary form was triaxial; if so the mass and percentage losses have been overestimated.

8. W.A.M. 12884. Found about 18 km W. of Notting railway siding. The lustre is dulled by abrasion. This is one of the few specimens examined which tends to bulge slightly anterior to the rim. The posterior surface has some lunate scars and small pits. The equatorial zone, which averages 15 mm wide, has abundant gutters which are variable both in orientation and form (some parallel to flight path, others vermiform or branching). The anterior surface has some gutters and bruise scars shallowed by abrasion.

Arcs of circles do not fit closely the profiles of the posterior surface and have radii in the range 3.1-3.3 centimetres. Because of these uncertainties, a mean figure was used to calculate the primary body as a sphere.

9. W.A.M. 12993. Turned up by a bulldozer from shallow depth in sandy soil about 19 km N. of Ongerup in 1968. This specimen has much the same form and unusual features as No. 3 above. There is no rim or defined limit to the equatorial zone but there is a band of distinctive sculpture. The posterior surface is somewhat irregular as the result of flake losses and has an area of deep pitting. Gutters are present only on the anterior surface with a suggestion of circumferential pattern. The anterior surface is strongly wedged (Fig. 2), thus presenting very different profiles when viewed from different directions. Arcs of circles fit profiles of the posterior surface fairly well and continue to fit over parts of the "equatorial zone".

10. Geological Survey of W.A. R.2024. Found near Cuballing. Described in detail and figured by Baker (1966) prior to its donation to the Survey collection.

11. W.A.M. 12843. Found at Graball, E. of Narembeen. Described and figured by Baker (1963) prior to its donation to the Western Australian Museum. Because the percentage mass loss is the highest for any of these large cores, derivation from an oblate spheroid is suspected and this is supported by lens measure readings. However, because of the extensive etching and minor artificial damage to the posterior surface, no re-estimation of the primary body on that basis has been attempted.

12. Figs. 2 & 3. W.A. Government Chemical Laboratories Mineral Division collection 1678. Found about 5 km S.E. of Corrigin in 1955. The posterior surface is relatively well preserved and shows minor sculpture ranging from barely perceptible schlieren through distinctly etched flow swirls to short gutters and a single elongate gutter paralleling the pattern of a flow swirl. The rim is reasonably defined and regular except where affected by minor flake losses and the development of an area of deep pitting. The equatorial zone has some gutters oriented normal to the rim; its limit is ill-defined. The anterior surface is distinctly wedged and shows a few gutters.

13. Cast W.A.M. 13237. Original owned by Mr. R. Kirkpatrick. who found it on Mr. C. Adams' property "Marambeena", c. 25 km S.W. of Chillilup in 1972.

Neither the rim nor the anterior limit of the equatorial zone is clearly defined. The form of the posterior surface is considerably modified by the natural loss of small flakes. The equatorial zone is c. 10-18 mm wide and the minor sculpture is principally short gutters, variously oriented. The anterior surface is roundly and asymmetrically wedged parallel to the longer diameter. The low specific gravity (2.410) is probably to be ascribed to bubble cavities. The arc of a circle will fit well only to the transverse profile and the radius of that arc has been used in calculating the primary body as a sphere.

14. W.A.M. G8978. Described by Simpson (1939) with two unspecified views, the first an elevation with anterior surface towards top of page, the second the (presumed) anterior surface showing artificial damage. Bowley (1945) concluded that the specimen had been found between Narrogin and Merredin (Fig. 1) and this is feasible because several unusually massive australites have since been found within that general area.

15. In Geological Survey of W.A. collection. Found about 16km N.W. of Ongerup. Fully described and figured by Baker (1967).

16. Found near Kalgarin in 1960. The finder shattered the core by a heavy blow with a hammer. The larger pieces were given to Mr. R. Pugh, who re-assembled them, but clearly many small fragments were not recovered.

Dismemberment disclosed a breached bubble cavity 6 mm diameter located just off the axial line and slightly closer to the posterior than to the anterior surface. Another cavity 2 mm diameter and a few smaller ones were also revealed. Fragments macroscopically free of fractures were selected for determination of specific gravity, the choice being thereby limited to three pieces of total mass 12.5 grams. The specific gravities are in the range 2.435-2.442 with a weighted mean 2 439. These fragments constitute only about 10% of the material, and because of exposure of bubble cavities, the specific gravity is biased towards the higher value for australite glass rather than representative of the australite as a whole.

The reassembled specimen is sub-spherical (mean diameter/thickness 0.93) with a defined but rather sinuous rim and equatorial zone. The posterior surface has a meridional strip from rim to rim containing short transverse gutters.

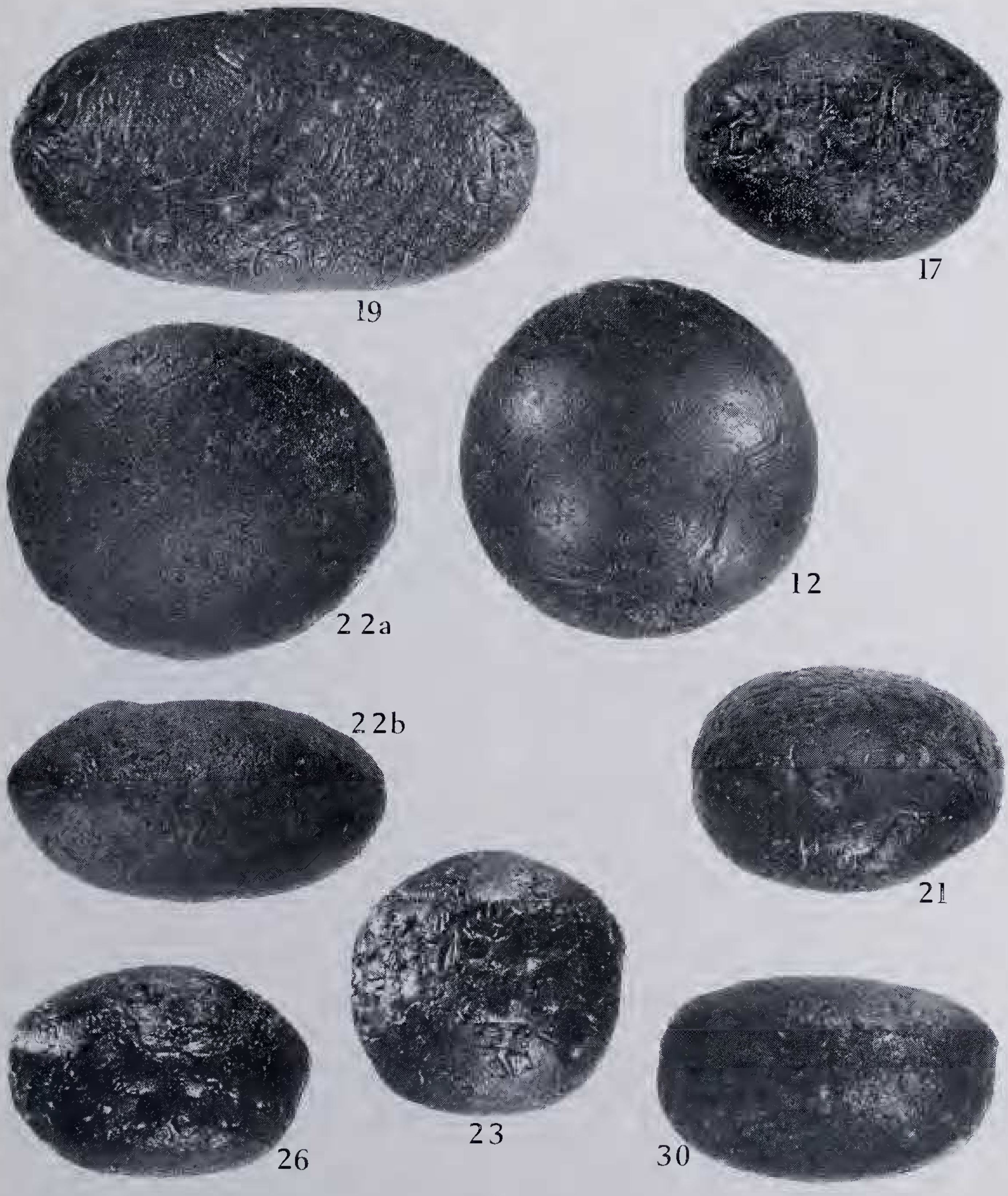

Figure 3.—Australites from Western Australia numbered as in text and Table 2. In all elevational views the anterior surface is towards bottom of page. 12.—Posterior surface showing etched flow swirls. Diameter 56.9-55.8 mm 17.—Elevation showing well defined equatorial zone with gutters and natural flake loss from posterior pole. Width c. 53.5 mm. 19.—Anterior surface with artificial damage at upper left and natural flake loss from rim at lower edge. Length 79.6 mm. 21.—Side elevation. Central area is artificially abraded. Width 51.4 mm. 22a.—Anterior surface. Length 61.3 mm. 22b.—Side elevation showing area of deep etching affecting the posterior profile. 23.—Elevation showing globular form. Thickness 43.6 mm. 26.—Side elevation. Length 50.4 mm. 30.—Side elevation. Length 54.7 mm.

The equatorial zone also has gutters, some of which are meandrine. Because of the history of this specimen, all quantitative estimates of the core and its primary body should be regarded as very approximate.

17. Fig. 3. W.A.M. 3491. Found near Corrigin. Fenner (1934, 1955) made brief references to this specimen, in the second publication under the incorrect accession number 3441. Chapman (1964, Fig. 11) illustrated a side elevation chosen to emphasise the degree of imperfection (flake losses from posterior pole and rim and an extensive area of deep pitting) when compared with cores from elsewhere. The rim is fairly well preserved and regular. The posterior surface has some circular groove structures and some roughly circumferential gutters near the periphery. The equatorial zone has gutters oriented approximately normal to the rim. On the anterior surface, short gutters near the equatorial zone are oriented more or less circumferentially. Except in areas of imperfection noted above, arcs of circles fit fairly well the profiles of the posterior surface.

18. Australian Museum, Sydney DR:7533. Found at Lake Grace. The form is extremely irregular and asymmetrical as the result of natural flake losses from both posterior and anterior surfaces, and artificial losses caused by a severe blow on the posterior role of the specimen. The rim is represented only by worn remnants and the limit of the equatorial zone is poorly defined. Short gutters, variously oriented, are present on the equatorial zone. A complex of oval pits and short gutters is present on the major anterior flake scar. The specific gravity is well below average for large cores from Western Australia. No reliable estimate of the primary body is possible.

19. Fig. 3. W.A.M. 12264. Found about 26 km E. of Kulin in 1960. The dull posterior surface contrasts with the "lacquered" appearance elsewhere. Some circular and lunate scars and two small areas of gutters on the posterior surface have been shallowed by abrasion. The rim is ill-defined and sinuous and there is no distinct anterior limit to the equatorial zone, though gutters show the usual orientation approximately normal to the rim. A reasonable estimate of the parental form is possible.

20. W.A.M. 12960 (formerly Geological Survey of W.A. collection 11177). Salient details and an illustration of the anterior surface were given by Simpson (1902, p. 81 and Pl.I), who described the site of find as being "100 miles East by South of Weld Springs, or say about Lat. 25° 30′ S, and Long. 123° 0′ E.", a point closely coincident with Lake Buchanan. The W.A. Museum catalogue records that the specimen was found by the Calvert Expedition of 1896-7. The presumed year of find was 1896 because Lake Buchanan was named by Surveyor L.A. Wells of the Calvert Expedition in that year (pers. comm. from W.A. Surveyor General's Department). An oblique view emphasising the posterior surface was figured by Thorp (1914 Pl. XVIII Fig. 6). who added incorrectly that the specimen was found at Weld Springs by the explorer John Forrest; Fenner (1934) repeated the statement regarding the finder. Forrest was not associated with either the Calvert Expedition or the subsequent relief and search efforts; he had named The Weld Spring 22 years previously.

The fore-going is given in some detail to emphasise that the place and circumstances of find of this core are well authenticated. The site of find should not be stated as "Weld Springs" (i.e. The Weld Spring); nor should Lake Buchanan be confused with Lake Buchan, which is more than 900 km distant to the south west.

The rim of the core is well defined but there is no distinct limit to the equatorial zone. The posterior surface, where not affected by extensive but shallow artificial flake loss, has some circular pits transitional to circular gutters set in a surface of small scale "hammered metal" appearance. The anterior surface is much like the posterior but with the etching rather more advanced.

21. Fig. 3. S.A.M. T191. Fenner (1955) reported briefly on this specimen. Despite the fairly bright lustre, the core appears to have suffered considerable physical erosion. Small natural flake losses, an extensive but shallow artificial flake loss, and artificial abrasion of a small area on the equatorial zone have further contributed to the general irregularity and imperfection of the form. No rim is present and the assumed orientation depends partly upon the greater degree of asymmetry and the more abundant gutters on that surface chosen as anterior. Gutters, variously oriented, are also present on the equatorial zone and on the periphery of the posterior surface. Estimates of the form of the primary body with any reasonable degree of reliability are not possible.

22. Fig. 3. Owned by Mr. F. Davis, who found it on Avon Location 7501 about 8 km E.N.E. of Wickepin East.

The lustre is somewhat dulled by abrasion. The rim is irregular and poorly defined as is also the anterior limit of the equatorial zone. Etched strips on the posterior surface contain short gutters, mostly transverse to the length of the strips. Gutters on the equatorial zone are oriented at right angles to the rim and others outline the bottoms of oval flake scars. The anterior surface has a few gutters, etched schlieren and pits. The transverse profile of the posterior surface is symmetrically wedged as the result of natural flake losses (c. 8 g) and the longitudinal profile is also affected by flake loss. The estimates of the primary body are therefore very approximate.

23. Fig. 3. Geological Survey of W.A. collection 1/5327. Found at Narembeen. This core is closely equidimensional, having a thickness/mean diameter ratio of 0.95. The posterior surface has a complex of small gutters in depressed, deeply etched areas and other gutters tend to be circumferential near the rim. The rim is well defined. Minor sculpture of the equatorial zone is principally gutters, variously oriented. The anterior surface is asymmetrically wedged and

has some small gutters with tendency to circumferential orientation. Gutters are more abundant on the posterior than on the anterior surface, an unusual occurrence. The form of the primary body cannot be determined reliably because of the deep etching of the posterior surface.

24. W.A.M. 10613. The posterior surface and equatorial zone are similar to those of No. 21 above. The anterior surface has abundant gutters and a minor artificial flake scar. Most gutters are sharply defined and all are narrow (c. 0.2 mm). The forms of the longitudinal and transverse profiles had to be estimated from surviving patches of original surface and the results differed by 2 millimetres. The parent mass might have been a slightly prolate spheroid but has been calculated as a sphere using the mean figure as radius.

25. S.A.M. T427. Initially in the collection of Mr. S. F. C. Cook. Fenner (1934, 1955) made brief references to this specimen from Norseman and illustrated the posterior surface. Little can be added because of the extremely corroded state of the specimen. As is well shown by Fenner (1934 Pl. IX E2), the posterior surface lost a flake from the polar area and subsequently developed such a degree of pitting as to approach the appearance of hammered metal. Such sculpture with patches of interrupted, etched schlieren extends over the entire surface. The rim and the limit of an equatorial zone c. 1 cm wide are still recognisable and within the equatorial zone are modified flake scars. The form of the primary body must needs be judged by that of the annular and much corroded remnant of posterior surface.

26. Fig. 3. W.A.M. 12090. Found by Mr. F. Basset about 3 km E. of Brookton in 1961. The form is somewhat irregular as the result of minor flake losses. The posterior surface has a narrow band running obliquely from rim to rim containing short gutters and terminating in deeply pitted areas at each end. The rim and the limit of the equatorial zone c. 1 cm wide are poorly defined. The equatorial zone has gutters oriented normal to the rim and outlining the bottoms of oval flake scars. The anterior surface is distinctly asymmetrical in profile; its central area has a complex of short gutters. Flake losses could not be assessed with confidence but the percentage represented would be small.

27. W.A.S.M. 10199. This australite from an unspecified locality in the Eastern Goldfields of Western Australia has been described by Baker (1967). Additionally, an assessment of the primary body has been attempted.

28. W.A.S.M. 8950. For detailed description and illustrations of this specimen from 42 km E. of Narembeen, see Baker (1961). Because of the deeply corroded condition of this core the estimate of the form of the primary body is very approximate.

29. W.A.S.M. 9421. Found by Mr. J. P. Parker about 11 km S.E. of Salmon Gums in 1962. Described by Baker (1967). An estimate of the form of the primary body has been attempted.

30. Fig. 3. Owned by Mr. C. B. C. Jones of Hampton Hill Pastoral Station. Found on the station about 10 km W. of the abandoned Kurnalpi townsite. This specimen evidently suffered some wear in transport before enclosure in alluvium because natural flake scars are well rounded yet the entire surface now has a uniformly bright lustre. There has been no artificial damage. Natural flaking has removed a continuous length of half the rim; the remainder is well defined and regular as is also the limit of the equatorial zone. Both posterior and anterior surfaces have etched lunate and circular bruise scars. The equatorial zone has a few gutters oriented normal to the rim and etched flake scars. A fair estimate of the primary body is possible; flakes account for only about 1% loss.

31. S.A.M. T509. Formerly in the collection of Mr. S. F. C. Cook. Illustrations of this specimen given by Fenner (1955) include an elevational view showing the sharp, well-preserved rim (Pl.VIII-16). The surface has a bright lustre. The rim is complete except for a minor natural flake loss. The posterior surface has some short gutters with tapered ends and V-shaped cross sections reminiscent of gash fractures and they tend to radial orientation. The Lake Ballard core (No. 6, Table 2) is the only other of these large Western Australian specimens having such gutters on the posterior surface, but their development is much further advanced in that example (Cleverly 1971 Fig. 1). The equatorial zone has well-defined gutters of U-shaped section oriented normal to the rim. The anterior surface is almost free of minor sculpture.

32. W.A.M. G7566. This fragment is included for completeness of record. The entire anterior surface and one end have been removed by artificial fracture. The bluntly wedged remnant has angle c.115° and by analogy with other artificially broken specimens the edge was probably immediately beneath the anterior surface as found. Reconstruction suggests that the mass prior to artificial fracture certainly exceeded 100 g, and possibly attained 115 grams. The dull abraded remnant of posterior surface has small depressed areas containing narrow gutters and small areas of deep pitting extending to the equatorial zone, the remnant of which has some gutters oriented normal to the rim.

Round core of unknown provenance

Fenner (1955) figured the artificially damaged posterior surface and a side elevation (Pl.VII Figs 5 and 6 respectively) and stated that the specimen had been found in the Western Australian Goldfields. The owner, Miss K. D. Blackham of Adelaide, is insistent that neither the finder nor site of find is known to her; the specimen might have come from any of the gold mining localities with which members of the family had early associations, viz. Ballarat (Victoria), Teetulpa (South Australia), Coolgardie and Kalgoorlie (Western Australia).

The dimensions are 52.7 x (51.3)51 x 44.5 mm, the mass 153.96 g (c.168 g prior to artificial damage), and the specific gravity 2.399. The specific gravity is distinctly lower than that of any other australite of mass exceeding 100 g for which values are available. The figure is much closer to average values in Victoria than those elsewhere (Baker 1969 Fig. 2), but the value for an individual australite has very limited significance. Although 2.399 is almost the mean value for Port Campbell, Victoria specimens, it nevertheless lies within the range shown by australites from the Kalgoorlie district, Western Australia (Chapman *et al.* 1964 Fig. 7). The general aspect of the specimen is that of a water worn pebble. The entire surface is dulled by abrasion and the bruise scars show various degrees of freshness or of shallowing by abrasion. Possibly only one episode of transport with intermittent bruising is represented.

No clear indication of provenance was recognised but an area in which true alluvial gravels existed (i.e. Victoria or possibly Teetulpa) seems rather more likely than arid interior Western Australia. Victoria is the more likely because the known area of occurrence of unusually massive australites (Baker 1969) overlaps the alluvial goldfields; Teetulpa is nearly 300 km distant from the Karoonda-Lowaldie area, from which have come the only two cores of mass exceeding 100 g yet reported from South Australia.

Discussion

The Lake Buchanan core (No. 20) was the first recorded australite of mass exceeding 100 grams (Simpson 1902). The number of such specimens known grew slowly to 24 (Baker 1972). The present known total is 41, comprising 32 from Western Australia (Table 2), six from Victoria (Baker 1969, 1972), two from South Australia (Fenner 1955) and one of unknown provenance (this paper). Most of the recent increase is accountable to previously unpublished specimens in the W.A. Museum collection and to specimens which are privately owned. An australite said to have been found in the vicinity of Eucla and of mass c.142 g (Fenner 1934 p. 78) has not been included in the total because the report is hearsay only, though the locality would fit well the distribution pattern referred to below.

The number of additional specimens in private hands is unknown but probably considerable to judge by the response to some very limited publicity. A brief news item submitted to a Kalgoorlie radio station concerning the discovery of the 437 g (No. 1) specimen, had the immediate result that No. 16 was offered for examination; an article on australites published for the writer by the *Narrogin Observer* brought in response Nos. 4 and 22.

The sites of find of the Western Australian specimens (Fig. 1) comprise a south west group and scattered occurrences to the east and north east. The south west group lies entirely within the main wheat belt, where there is a settled population and where the land is periodically seen and shallowly embedded objects are brought to the surface during cultivation. To the immediate east of this belt, both north and south of the principal Perth-Kalgoorlie road and rail links, there is no permanent settlement and a corresponding gap in the distribution pattern. Further east again is the narrow strip of country containing a few widely spaced centres of population associated with mining in the north and agriculture in the south (Salmon Gums). The two most northerly australites were chance discoveries of a mineral exploration party outside the active mining area and of an exploration expedition in country which is still on the extreme fringe of extensive-type pastoral development more than seventy years later. There is thus such a close positive correlation between the sites of find and the distribution of human activities that it is tempting to dismiss the first distribution as a direct result of the second. However, there is good evidence, at least for the Eastern Goldfields region, that australites of mass exceeding 100 g are extremely rare.

The most important evidence is the private collection of Mr. D. L. Tillot on containing nearly 11 000 located australites gathered from a broad belt extending up to 200 km north and south from Kalgoorlie; the most massive specimen in this collection is of only 58.1 grams. The C. B. C. Jones family collection has been gathered from the country immediately E.N.E. from Kalgoorlie and is numerically at least equal to that of Mr. Tillotson; the most massive specimen is of 101.12 grams (No. 30 this paper). The Cook collection of more than 5 000 specimens, now in the South Australian Museum (Fenner 1949), was gathered from a more extensive area also centred upon Kalgoorlie; only two specimens (Nos. 25, 31) qualified for inclusion in this paper. Smaller official and private collections could also be cited as well as the thousands of australites which pass through the hands of commercial lapidaries. The most massive of about 5 000 specimens handled by one Kalgoorlie lapidary in recent years has mass 59.1 grams. This general region has twice been intensively prospected, earlier for gold and latterly for base metals. Inclusive of the numerous small private collections resulting from these activities it is likely that 40 000 australites have been recovered from the Eastern Goldfields, yet only six are known of mass exceeding 100 grams.

Further to the north, Earaheedy and other pastoral stations to the west and south-west of Lake Buchanan are represented in available collections by more than 1 300 specimens of which the most massive is a 74.2 g specimen from Wongawol (No. 22 in E. S. Simp on collection held at W.A. Museum).

The Western Australian wheat belt extends a further 400 km north-westerly from the australite occurrences shown in Fig. 1B, presumably with equally good opportunities for observation of australites, yet no specimen of mass exceeding 100 grams is known to have been recovered there. The centering of the infall of unusually massive australites in the south west of Western Australia thus appears to be a reality, but the area of their occurrence is almost certainly larger than is shown in Fig. 1B, the eastern boundary having resulted from the circumstances of collection.

The coastal strip flanking the wheat belt to the west and south was omitted from consideration above. It has relatively high rainfall and much of it is heavily timbered. Though it has the highest density of human population for any part of the State, it is poorly represented in australite collections. This paucity of known australites is likely to be, at least partially, the consequence of an adequate drainage and vegetation cover when compared with the extensive cultivated areas and bare, semi-arid terrain further inland.

An almost cylindrical australite fragment (W.A.M. 13202) of mass 42 g from the Albany district (Fig. 1A) is the central portion of a stout-waisted dumbbell; the width and thickness at the waist are 29.2 mm and 27.2 mm. The analogous dimensions of the 151 g Ongerup dumbbell are 33.2 mm and 26.8 mm (Baker 1967). It is thus likely that the fragment represents an australite of which the mass attained 100 g, so that the area of infall of unusually massive specimens should be extended to the south coast.

Knowledge of australite distribution is very imperfect and the number of specimens concerned in the present paper is very small. Extreme caution is therefore necessary before acknowledging the existence of a pattern in the distribution and the following is offered with some diffidence.

The six Western Australian australites of mass exceeding 200 g were found in a belt extending S.S.W. from Lake Ballard, i.e., in a direction approximately at right angles to the northern boundary of the australite strewnfield (Baker 1969b Fig. 1). When the distribution of the most massive specimens of other mainland states is also considered (Baker op. cit.) the sites are seen to occur in areas distant from that boundary, the south western portion of the continent being the most distant and extensive and containing the sites of 17 of the 20 most massive australites known. These observations suggest the possibility of a mass grading away from the strewnfield boundary. If the direction of flight is to be related to such a grading, it is at variance with the conclusions of Baker (1969a), McColl and Williams (1970) and Chapman (1971). It would be of interest to know the distribution of a less massive category, say 50-100 g, and whether there are large overlaps in the distribution of successive categories as would suggest the entry into the atmosphere of a range of masses either continuously or at various points along a flight path. The greater numbers in the less massive categories should provide more reliable data.

The mean specific gravity of all 32 specimens under consideration has little significance because of the wide area of occurrence represented, but the more circumscribed south west group of 25 specimens warrants brief consideration. With the exception of Nos 2, 13 and 18, the low specific gravities of which are probably attributable to bubble cavities, specimens of this group have specific gravities in the narrow range 2.420-2.439, a variation of less than 1%. This degree of constancy might suggest a distinct population within the australite shower but another explanation is more probable. The heterogeneity arising from irregular distribution of bubble cavities of various sizes in australite glass may be expected to be evident in groups of small australites as a considerable variation in their specific gravities. For groups of increasing size from any one area, the amount of variation arising from this cause may be expected to decrease until the most massive specimens approximate to the bulk specific gravity of the material and only occasional specimens show significant departures from the mean value, i.e. the larger samples of a heterogeneous material are more likely to be truly representative. The constancy of values could thus arise from the large sizes of the specimens.

The weighted mean specific gravity of the 25 specimens in the south west group of total mass 4.2 kg is 2.427. This is a lower mean value than for other measured groups in Western Australia (Baker 1969b) but the group is located further south than the others. Because these large cores have lost stress shells and are generally quite eroded, they retain virtually no surface glass from which constituents could have been volatilized during atmospheric flight as occurs from flange glass. The low mean specific gravity cannot therefore be attributed to that cause.

Globular, more or less equidimensional cores are well represented in the south west group. They reach their extreme development in Nos. 3 and 9 which lack a rim. Other specimens (Nos. 8, 16, 23), though rimmed, have even higher thickness/diameter ratios and calculated losses are very low. After allowing for a stress shell, thickness losses of 4-9 mm leave little or nothing for ablation losses. It has to be conceded as a possibility that these cores, all of which are round or only slightly oval, developed from prolate spheroids which travelled with the long axes parallel to the flight paths. In calculating the primary bodies as spheres their primary masses would be underestimated and likewise the losses from them.

No detailed analysis of the loss figures has been attempted because the number of reliable estimates available for any one shape type is so small. The loss figures are generally low. The average volume loss is only 46% compared with 56.5% for 23 perfectly preserved buttons from Port Campbell, Victoria (Baker 1962), though the loss of a stress shell did not contribute at the latter locality and terrestrial losses were insignificant. In a very general way, the better preserved cores have the higher loss figures. There may therefore be errors not only in the estimated dimensions of the primary bodies but also in the shape types ascribed to them.

Acknowledgments.—For the loan of australites for examination I thank the Trustees of the Western Australian Museum and Dr. C. Pearson, the Trustees of the South Australian Museum and Miss J. Scrymgour, Mr. F. L. Sutherland and Miss J. Hingley of the Australian Museum, Sydney, The Director of the Geological Survey of W.A. (Mr. J. H. Lord), The Director of the W.A. Government Chemical Laboratories (Dr. L. W. Samuel), Miss K. D. Blackham of Adelaide, Mrs. H. Biggin of Kondinin, Mr. P. Repacholi of Kondinin, Mr. R. Pugh (Headmaster Coolgardie), Mr. F. Davis of Kulin East, Mr. C. B. C. Jones of Hampton Hill Pastoral Station and Mr. R. Kirkpatrick of Mandurah.

Dr. George Baker of Melbourne kindly read the first typescript of this paper and it has been distinctly improved by the amendments which he suggested.

References

Baker, G. (1956).—Nirranda strewnfield australites, south-east of Warrnambool, Western Victoria. *Mem. Nat. Mus. Vict.* 22: 1-172.

——— (1957).—The role of australites in aboriginal customs. *Mem. Nat. Mus. Vict.* 22: 1-26.

——— (1959).—Tektites. *Mem. Nat. Mus. Vict.* 23: 5-313.

——— (1961).—A naturally etched australite from Narembeen, Western Australia. *J. Roy. Soc. West. Aust.* 44: 65-68.

——— (1962).—The largest known australite and three smaller specimens from Warralakin, Western Australia. *J. Roy. Soc. West. Aust.* 45: 12-17.

——— (1963).—Round australite core from Graball, Western Australia. *J. Roy. Soc. West. Aust.* 46: 57-62.

——— (1966).—The largest known dumbbell shaped australite. *J. Roy. Soc. West. Aust.* 49: 59-63.

——— (1967).—A second large dumbbell shaped australite, Ongerup, Western Australia, with notes on two other large australites. *J. Roy. Soc. West. Aust.* 50: 113-120.

——— (1969a).—Five large australites from Victoria Australia, and their relationships to other large forms. *Mem. Nat. Mus. Vict.* 29: 53-64.

——— (1969b).—Australites from Mulka, Lake Eyre region, South Australia. *Mem. Nat. Mus. Vict.* 29: 65-79.

——— (1972).—Largest australite from Victoria, Australia. *Mem. Nat. Mus. Vict.* 33: 125-130.

Bowley, H. (1945).—Australite observed to fall at Cottesloe—a correction. *J. Roy. Soc. West. Aust.* 29: 163.

Chapman, D. R. (1964).—On the unity and origin of the Australasian tektites. *Geochim. et Cosmochim. Acta* 28: 841-880.

——— (1971).—Australasian tektite geographic pattern, crater and ray of origin, and theory of tektite events. *J. Geophys. Res.* 76: 6309-6338.

Chapman, D. R., Larson, H. K. and Scheiber, L. C. (1964).—Population polygon of tektite specific gravity for various localities in Australasia. *Geochim. et Cosmochim. Acta* 28: 821-839.

Cleverly, W. H. (1971).—An oval australite core from Lake Ballard, Western Australia. *J. Roy. Soc. West. Aust.* 54: 14-16.

Fenner. C. (1934).—Australites, Part I. Classification of the W. H. C. Shaw Collection. *Trans. Roy. Soc. S. Aust.* 58: 62-79.

——— (1940).—Australites, Part IV. The John Kennett collection with notes on Darwin glass and bediasites. *Trans. Roy. Soc. S. Aust.* 64: 305-324.

——— (1949).—Australites, Part V. Tektites in the South Australian Museum, with some notes on theories of origin. *Trans. Roy. Soc. S. Aust.* 73: 7-21.

——— (1955).—Australites, Part VI. Some notes on unusually large australites. *Trans. Roy. Soc. S. Aust.* 78: 88-91.

McCall, G. J. H. (1965).—The heaviest recorded australite. *Aust. J. Sci.* 27: 267.

McColl, D. H. and Williams, G. E. (1970).—Australite distribution pattern in southern central Australia. *Nature* 226: 154-155.

Simpson, E. S. (1902).—Notes from the Departmental Laboratory. *Geol. Surv. West. Aust. Bull.* 6.

——— (1939).—A second australite observed to fall in Western Australia. *J. Roy. Soc. West. Aust.* 25: 99-100.

Thorp, C. G. (1914).—A contribution to the study of australites. *J. Nat. Hist. Sci. Soc. West. Aust.* 5: 20-43 and Pls. XVIII-XXIII.